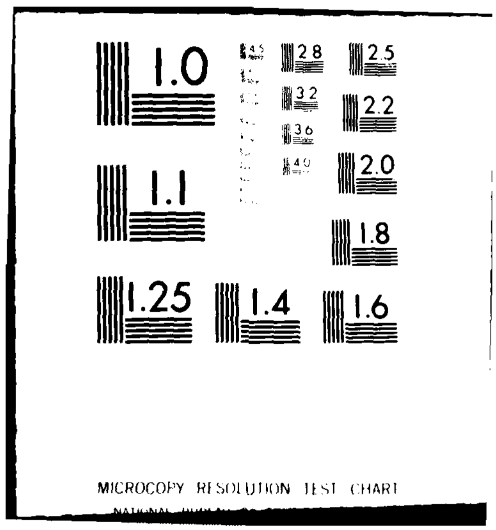
AD-A090 405 ARMY TANK-AUTOMOTIVE RESEARCH AND DEVELOPMENT COMMAND--ETC F/G 19/3
VEHICLE MOBILITY OR FIRING STABILITY. A DELICATE BALANCE.(U)
JUN 80 F B HOOGETERP, R R BECK
NL

UNCLASSIFIED

1 OF 1
AD
A090405

END
DATE
FILMED
11-80
DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
MICROCOPY RESOLUTION TEST CHART

VEHICLE MOBILITY OR FIRING STABILITY. A DELICATE BALANCE

JUN 1980

*FRANCIS B./HOOGTERP, MR.
RONALD R./BECK, DR.
TANK-AUTOMOTIVE RESEARCH AND DEVELOPMENT COMMAND
WARREN, MI 48090

INTRODUCTION AND MOTIVATION

The Army's current interest in mounting a large caliber cannon on a light weight tracked armoured combat vehicle has precipitated the evaluation of numerous vehicle-weapon system configurations. Yet the same question has continually resurfaced: "Is it feasible to mount a large cannon on a lightweight vehicle chassis?" Questions such as this can seldom be answered uniquely. The answer in this case depends on whether there is a strong enough need for such a system and on its mission, if and when it is fielded. The design community's job is to come up with the most workable weapon system concept within the given constraints and to attempt to relate the performance of this concept to that of some known combat vehicle. If this task is executed properly, then and only then, can the question be answered in a satisfactory manner.

The mission profile of such a vehicle dictates that it must be capable of destroying enemy tanks. Against the heavily armoured tanks of modern armies, this requires a relatively large cannon. This vehicle would also be expected to perform a reconnaissance role. In order to accomplish this successfully, the vehicle must possess superior mobility . A further requirement is that it shouldn't cost as much as a conventional tank. These restrictions are most easily satisfied by keeping the vehicle weight as low as possible. This tends to keep the cost per vehicle down and allows a fairly high horsepower per ton ratio. Any tactical gain obtained from increased vehicle acceleration performance, given by the high horsepower per ton ratio, will be

quickly eroded unless a correspondingly good cross country ride performance is designed into the vehicle.

The overall vehicle survivability can be further enhanced by allowing the cannon to be operated in burst fire mode. This can increase the kill probability significantly in a surprise attack on an enemy tank. This increased kill probability can only be achieved, however, if the vehicle's stabilization system is capable of keeping the gun pointed at the target in the aftermath of the initial firing of the cannon. The desirability of burst fire capability is the major motivation for studying the platform firing stability problem. If the firing platform (i.e. the vehicle) remains more nearly stationary while the gun is recoiling from a previous firing, the stabilization system will be able to keep the gun on target more easily. A second reason for investigating the transient motions of the vehicle due to firing the cannon is the possibility that this motion might have an adverse effect on the crew of the vehicle. This is a problem that is somewhat unique to this type of vehicle-weapon system. The fact that this is a concern is testified to by gunners who have fired the M551 Sheridan gun (17.5 Ton with 152mm gun).

The design of a lightweight vehicle to carry a large cannon is not a new venture for the U.S. Army. Development of the M551 Armoured Reconnaissance/Airborne Assault Vehicle (also known as the Sheridan) was initiated in 1959. Approximately 1700 Sheridans were produced at the Cleveland Tank Automotive Plant by General Motors Corporation for the U.S. Army from 1966 through 1970 (1). The Sheridan is armed with a 152 mm main gun and the final design weighed in at approximately 35,000 lbs. The main gun was perhaps larger than desired in some respects. This came about because of the design constraint to allow the launching of the Shileleaugh Missile. The 152 mm gun could also fire conventional ammunition but the vehicle's violent reaction to such firings, gave many a gunner a severe headache.

The Sheridan had the additional constraint placed upon its design that it be air dropable. This requirement, along with the necessity to carry (and fire) such a large cannon, caused certain compromises to be made in the vehicle design, adversely affecting the vehicle's cross country ride performance.

The purpose of this study was to perform a sensitivity analysis, using available simulation models, and to determine the most influential vehicle parameters with respect to a vehicle's cross country ride performance and to the firing stability of an initially stationary vehicle. It is anticipated that the results produced will be of assistance to the designer of future vehicle-weapon systems.

~~Before discussing the~~ results of the analysis, ~~we will discuss the~~ models and methodologies used. The model descriptions will be of necessity, somewhat brief, but will attempt to give an overall appreciation for the composition and complexity of each model. The ~~discussion will also touch upon~~ relevant model verification and validation efforts ~~that have been accomplished and thereby try to convey some level of~~ confidence in the results. ~~In addition to discussing the models~~, a short dissertation is included on the measures of effectiveness employed for evaluating the ride comfort and firing stability of the various concepts.

RIDE DYNAMICS MODEL

The vehicle dynamics model employed in this study is a two dimensional, 7 degree of freedom (for a vehicle with 5 roadwheels on a side) model. This model is implemented in FORTRAN and is combined with interactive data entry and postprocessor programs to provide a complete ride analysis package (4). Briefly the model consists of one second order differential equation describing the vertical motion of each roadwheel and two additional second order differential equations to describe the hull pitch motion about its CG and the vertical motion of the CG. The various spring and damper elements are treated in a piecewise linear fashion. Each of these suspension system elements is allowed to be represented by as many as nine separate (but connected) linear segments.

The track effects built into the model are rather simplistic but recent attempts to more completey validate the model have led to the inclusion of additional track effects by simply modifying the vehicle input characteristics slightly. A geometrical presmoothing of the profile of the terrain to be traversed is performed within the model and this "smoothed" profile is then used as the forcing function for each roadwheel. This presmoothing produces the approximate path that a slowly moving roadwheel would follow across the nondeflecting terrain. This results in very little modification of the milder profiles and will produce the most significant change to the sharpest obstacles. The effective vertical spring and damping characteristics of the combined roadwheel-track system are entered as piecewise linear functions. These spring and damper elements are attached between the modified terrain forcing function and the center of the roadwheel and are allowed to react only in the vertical direction.

One additional track effect was included for certain ride simulations performed. The rebound travels for the front and rear springs were restricted to 2.5 inches. The rationale for doing this is that the track prevents these roadwheels from dropping as far as

(293)

the intermediate wheels are allowed to. The 2.5 inch value was somewhat arbitrary but was selected after scrutinizing photographs of tracked vehicles traversing rough terrain. This effect can be pictured by imagining a vehicle being lifted completely clear of the ground. In this situation the front and rear roadwheels would actually be pulled upwards from their static positions by the tension in the track. In other situations, such as when the front wheel begins to cross a ditch, a limited amount of rebound travel does occur but never as much as would for an intermediate roadwheel.

For purposes of this paper, the evaluation of ride comfort will be considered only at the driver's station of the vehicle. In the concepts evaluated the driver sits nearly directly above the front roadwheel. The ride comfort of the driver for a particular velocity over a specified terrain profile is quantified in terms of the driver's vertical absorbed power. Absorbed power can be considered as being a frequency weighted rms acceleration, or more precisely as the power absorbed by the driver's body (2).

The frequency weighting is based on the average man's tolerance to acceleration at the various frequencies and was developed from extensive testing performed by the U.S. Army Mobility Systems Laboratory in the early 60's. A vehicle's limiting velocity for a given terrain is considered to be the lowest velocity at which the driver absorbs six watts of power (3).

Terrain roughness for the purpose of ride comfort evaluations is characterized by the rms (root mean square) of the profile measured in inches. A concept's ride limiting velocity, as defined above, is determined as a function of the terrain roughness. This relationship is considered to be the measure of the concept's ride comfort.

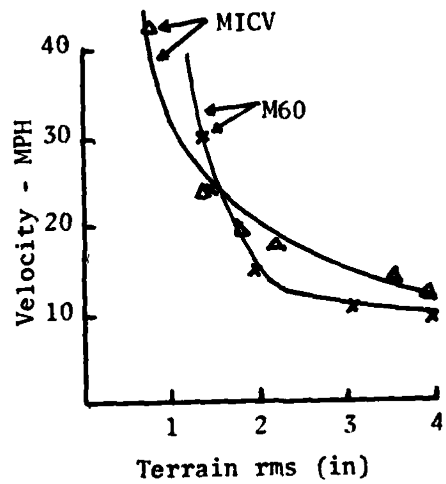


Figure 1
Ride Validation

Ride comfort curves for two standard Army vehicles are shown in Figure 1. The solid curves represent the results predicted with this model for the M60A1 tank and for the MICV armored personnel carrier. The individual points, marked with an "x", for the M60A1

(274)

were obtained from field tests conducted at Fort Knox in May 1979. The field tests from which the MICV data (denoted with a ▲) were obtained, were performed at Aberdeen Proving Ground in Nov. 1976.

PLATFORM FIRING STABILITY MODEL

The purpose of the platform firing stability evaluations was to assess the relative hull pitch and roll motions for various vehicle configurations. Two distinct models were employed to obtain the results presented here.

The first effort was performed using a very large, general purpose, mechanical system formulation and simulation program. This program termed DADS, which stands for Dynamic Analysis and Design System, had been implemented by personnel at the University of Iowa and was modified, under a contract with the US Army, to support this particular application (5). Input to the program consists of the inertial and geometric properties of each body to be modelled and the locations and types of the various joints that interconnect the bodies. Each joint may also have a spring and damper associated with it and the attachment points for these elements are described relative to the appropriate body CGs.

The DADS program uses the physical description of the system (in this case the vehicle and weapon data) and generates an appropriate set of equations to represent the system. This set of differential and algebraic equations is then numerically solved for the user.

It is impossible to do justice to the power and utility of DADS in the span of a few lines. This program is an exceptional exploratory modelling tool because of the sophistication and completeness of the automatically formulated models. DADS also routinely generates detailed recordings of every force, acceleration, velocity, and displacement in the system. The DADS formulation, for pitch plane motion only, for a vehicle with 6 roadwheels per side resulted in a system of 86 equations in 86 unknowns. This detailed formulation has been used successfully to evaluate the firing stability of numerous vehicle concepts.

Since this study required the simulation of numerous additional concept variations, it was decided to develop a less detailed, but more efficient to use, model. The experience gained with the more sophisticated DADS model, provided guidance for the new implementation as well as baseline results against which the results of the more efficient but simpler model could be verified.

295

The model developed (dubbed PFIRS) was made available as part of a completely interactive, user oriented simulation package (6). PFIRS includes equations for hull pitch, roll, vertical, and side to side motions. The vehicle data representation employed is identical to that used by the ride dynamics model described in the previous section, with the addition of the necessary roll related parameters, trunnion position data, and the firing reaction characteristics.

This model accomodates firing from an oblique position and allows the vehicle to be sitting on a sideslope for the direct side firing situation. Due to the original program requirement for sideslope firing analysis, small angle approximations were not made for the roll equations. The pitch angle was assumed to remain small, however. This assumption was justified by the actual simulations. The largest pitch angle encountered for any concept was 11 degrees and in the majority of the cases it was below 8 degrees.

It was also assumed that the tracks would not slide relative to the ground. This seems to be a reasonable approximation since actual tests of the M551 firing straight ahead from level, hard packed gravel, indicated a sliding of only 1/4" (7).

The roadwheel motions are not described by differential equations. Instead the roadwheels are assumed to remain in contact with the ground (through the track) unless the associated suspension system member develops sufficient force to lift it. The justification offered for this approach is twofold. First the deflection of the roadwheel-track combination is very small compared to the hull motions of interest and therefore the effect of the roadwheel deflections on the suspension system forces should be minimal. Second, this may actually be a more realistic representation since we assume that the ground is nondeformable, and certainly the roadwheel-track is at best marginally deformable. This would tend to suggest a position constraint on the roadwheel rather than the more traditional spring-damper connection between the roadwheel-track and the ground. This implementation has the added advantage that it reduces the number of first order differential equations, for a vehicle with 10 roadwheels, from 26 to 6.

The performance measure used here to study platform firing stability is the maximum change in the pitch displacement (or roll displacement for firing off the side) of the vehicle. This measure should give a good indication of stability for evaluating the possible application of a burst fire mode of operation to a vehicle weapon system. Obviously the horizontal acceleration at the gunner's eyepiece

also has an important influence on the gunner's reaction to firing the gun.

If the horizontal acceleration at the CG is also desired, it can be estimated quite accurately. This fact is illustrated in Table 1 and is due to the extremely short duration of the recoil force. The estimated column, labeled EST, was computed by simply taking the maximum recoil force divided by the gross vehicle mass. The column labeled DADS was simulated with the DADS firing stability model.

Concept	GVW tons	Gun Bore mm	Maximum Recoil ksi	Impulse Length msec	DADS g's	EST g's
I	16	75	38	54	1.2	1.19
II	16	90	67	46	2.2	2.09
III	42.5	90	67	46	0.81	0.79
M551	17.5	152	180	22	4.8	5.14

Table 1 Horizonal CG accelerations

It should be noted that the roll results throughout this paper are for firing directly off the side of the vehicle. The pitch results, on the other hand, are reported only for the vehicle firing straight ahead.

Vehicle	simulated with DADS degrees	simulated with PFIRS degrees	Test Results degrees
I	3.84	3.78	--
II	7.0	7.34	--
M551	4.2	4.13	3.8

Table 2 Comparison of Maximum Pitch by Model

The firing data available for validating these models were very limited. The only useable data found were for the M551 Sheridan firing conventional ammunition from its 152mm gun. The maximum pitch

(277)

angle recorded for firing straight ahead, while resting on hard packed gravel, was 3.8 degrees (7). This compares quite favorably with the results obtained both from DADS and from PFIRS which are shown in Table 2. Also presented in Table 2 are two other concepts (the same concepts as in Table 1) which illustrate the level of agreement achieved between the two models. These comparisons are offered simply to verify the implementation of the models. This should not be misconstrued to imply that the model has been validated. Certainly there is a need to add to the single validation point offered (i.e. the M551 firing).

RIDE COMFORT RESULTS

The Army's previous experience at mounting an oversize gun on a lightweight chassis resulted in a vehicle (the M551) with a vertical natural frequency of about 120 cpm. This is a very stiff suspension system when compared to the Army's other tracked vehicles. The natural frequencies and gross vehicle weights for several such vehicles are shown in Table 3.

VEHICLE	GVW ksi	FREQUENCY cpm
M113	24	92
M551	35	120
MICV	40	94
M60	112	74
XM1	120	72

Table 3 Typical Vertical Natural Frequencies

The effect of varying a vehicle's natural frequency on the vehicle's ride comfort is illustrated in Figure 2. Each of these concepts weighed 16 tons and had five roadwheels per side. Shock absorbers were positioned on the first, second, and the last roadwheels and a jounce damping ratio of 0.6 (the rebound damping was 2/3 of the jounce damping) was maintained for each concept. The only differences between concepts are in the force-deflection curves which describe each spring. The amount of jounce and rebound travel permitted each spring, however, also remained fixed at 14" and 5.5" respectively.

298

This portrayal supports the notion that if the suspension is made too soft the ride deteriorates on the harsher terrains. It is interesting to note also, that the 120 cpm version has the worst ride at all terrain roughness levels studied, yet this is precisely the design natural frequency of the M551.

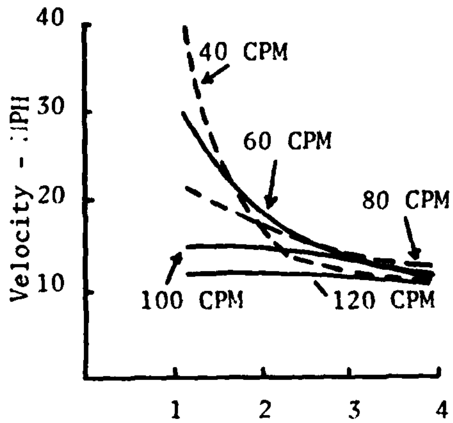


Figure 2
Natural Frequency vs. Ride

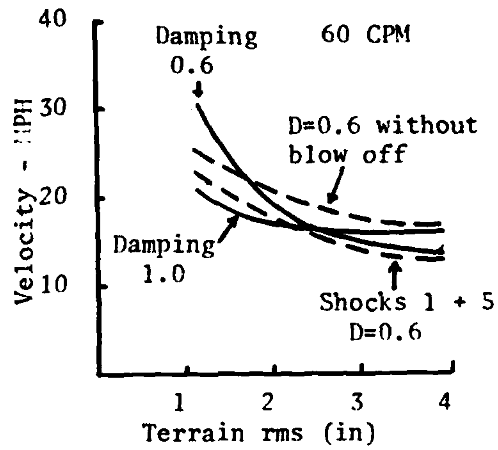


Figure 3
Damping vs. Ride

Figure 3 compares the baseline 60 cpm version of Figure 2 with three, otherwise identical, concepts with different damping characteristics. One version had a jounce damping ratio of 1.0 and blowoff at the same shock absorber velocity as for the baseline concept (resulting in a proportionately higher force). The second modification presented, maintained the damping ratio of 0.6 but removed the blowoff constraint. This permits the force produced by the shock absorber to increase without bound. The final concept shown in Figure 3 attains a jounce damping ratio of 0.6 with shocks only on the front and rear roadwheels. Blowoff is again provided and occurs at the same shock absorber velocity as before. This implementation provides an identical damping response, to a purely vertical motion, as does the baseline concept. This latter concept is of particular interest in view of the fact that the M551 has shocks only on the front and rear roadwheels.

The ride performance for various longitudinal CG positions is shown in Figure 4. It would appear that moving the CG forward can improve the ride comfort significantly over the lower rms terrains.

299

This result should be regarded with a word of caution. The ride comfort, as reported here, is measured only at the driver's location which is near the front of the vehicle. This implies that as the CG is moved forward, it is moved closer to the driver. Past studies have shown driver distance from the CG can greatly influence the magnitude of vertical acceleration that the driver would experience, and therefore also the power he would absorb. These results do not imply that the overall vehicle motion is reduced by moving the CG forward, but rather that the motion the driver feels is less severe.

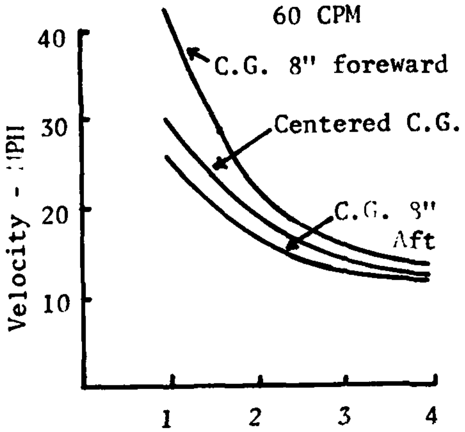


Figure 4
CG Position vs. Ride

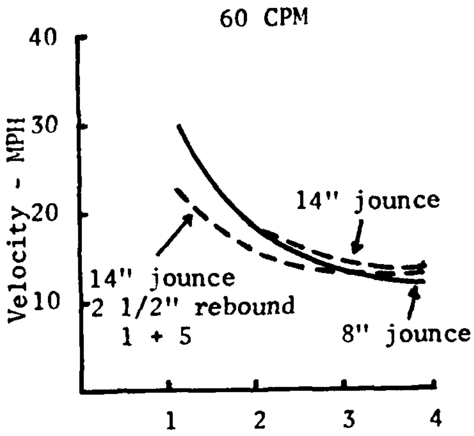


Figure 5
Wheel Travel vs. Ride

Figure 5 presents two final concept variations. The first comparison illustrates the rather expected impact of reducing the amount of jounce wheel travel. The baseline 60 cpm vehicle of Figure 2 is compared here to an otherwise identical vehicle with only 8" of jounce travel allowed for each roadwheel. The reduced wheel travel does not affect the ride on the milder terrains, but as the terrain roughness increases, the advantage of additional wheel travel becomes evident.

The effect that track tension can have on the front and rear roadwheels was discussed briefly in the model description section. It was stated that track tension greatly restricts the rebound travel of the front and rear roadwheels. The amount of rebound travel allowed would vary with different track-ground interface conditions but would, in general, decrease as track tension is increased. The final concept of Figure 5 shows the effect on ride quality of allowing only 2.5" of

300

rebound travel for the first and last roadwheels. All other vehicle parameters were identical to those of the baseline vehicle. The resulting deterioration in ride comfort could be simply attributed to model "sensitivities" but, more likely, it is an indication of how increasing track tension might affect a vehicle's ride quality.

PLATFORM FIRING STABILITY RESULTS

Many of the parameters that affect the ride comfort of a vehicle, also affect the stability of the vehicle when used as a firing platform. The vertical natural frequency of the vehicle, for example, significantly influences both performance measures, but in opposite directions. The softer suspension systems tend to ride better but provide a less stable platform and vice versa. Other vehicle parameters, on the other hand, may affect one performance criteria while having little or no impact on the other. A case in point is the longitudinal CG position which can affect the ride comfort to a considerable degree as attested to by Figure 4, but has virtually no effect on the firing response.

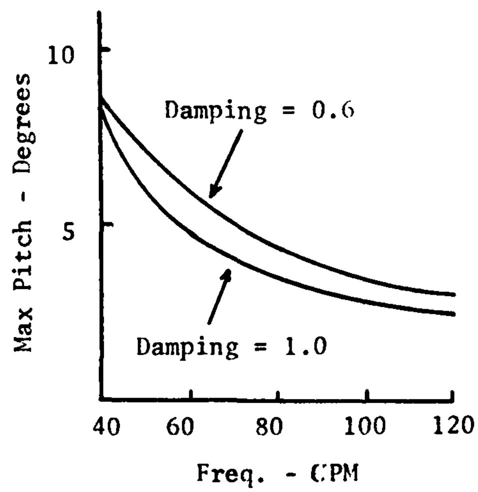


Figure 6
Natural Freq. vs. Firing

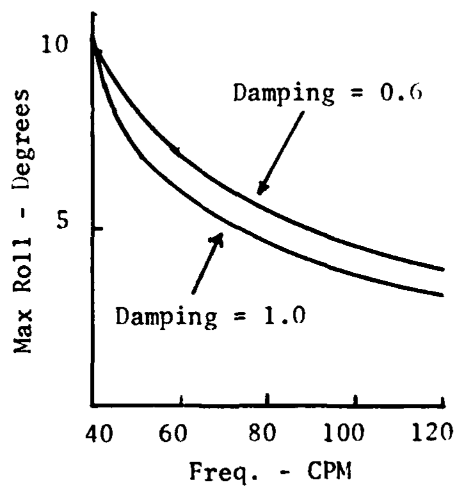


Figure 7
Natural Freq. vs. Firing

(301)

Figures 6 and 7 give the variation in platform response due to firing, as a function of the vertical natural frequency of the vehicle. Figure 6 shows the maximum pitch angle due to firing straight ahead. The concepts simulated to produce Figure 6 were also used to obtain Figure 7 which gives the maximum roll angle achieved when firing a single round straight off the side of the vehicle. These results are shown for two different damping levels with shock absorbers on the first, second, and the last roadwheels on each side.

One set of parameters that does not affect the ride comfort (at least as modelled here), but significantly impacts in the firing results, are the static CG height and the trunnion height above the CG. Figures 8 and 9 show the firing response variations when these two parameters are varied simultaneously. These results were for the 60 cpm concept with a 0.6 damping ratio. It is interesting to note the linear nature of the change, particularly for the pitch response. Also, in certain regions, the amount of roll motion produced by firing to the side, is unaffected by small changes in the CG height.

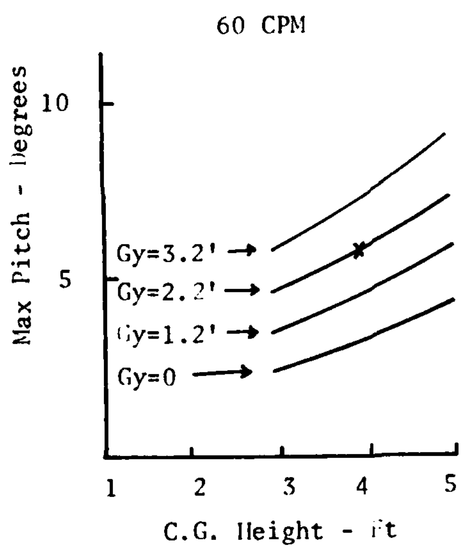


Figure 8
C.G. Height Effects

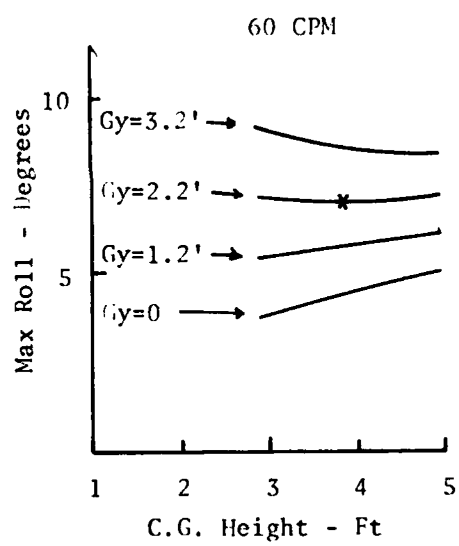


Figure 9
Trunnion & C.G.
Height Effects

The data points marked with an "x" on Figures 8 and 9 denote the baseline static CG height and trunnion position. These were the values used on the runs depicted in Figures 6 and 7.

(302)

DESIGN CASE STUDY

The M551 was selected as a trial case for application of the various parameter "sensitivities". This vehicle was chosen because it has a relatively poor cross country ride performance when compared to other tracked vehicles in its weight class. The objective was to improve the overall vehicle performance (as described by ride comfort and platform stability), but to stay within certain physical constraints that could not easily be changed on an existing vehicle.

The rules governing the effort were as follows. The mass distribution and geometric characteristics were considered fixed. In other words, vehicle parameters such as CG position, roadwheel spacings, and gun trunnion position were not allowed to be changed. Also the amount of jounce travel allowed for each roadwheel was considered fixed. Therefore the only design modifications that could be considered, were variations in the spring and shock absorber characteristics.

It is clear from the previous results that the ride quality could be easily improved by simply softening the suspension system of the M551. It is equally clear, however, that application of this tactic alone would result in a severe degradation of the platform stability. Since it is difficult to assess the comparative tradeoff values of the two performance measures, it was desired to significantly improve the ride quality while having little or no impact on the platform stability characteristics. The ride quality, rather than the platform stability, was selected for improvement since the extreme stiffness of the original suspension system provided a reasonably stable platform considering the magnitude of the reaction impulse of the 152mm cannon.

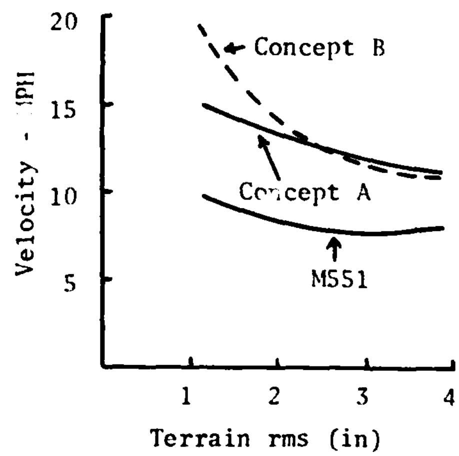


Figure 10
Case Study

Two distinct directions were taken in an attempt to improve on the ride performance. The first attempt concentrated on the damping characteristics only. The original springs were retained for this effort. It was conjectured that the stiffness of the suspension system would be suffi-

(303)

cient to restrain the vehicle's response to firing while modifications to the damping could possibly improve the ride quality.

The shock absorbers for each modification had lower rates in rebound than in jounce (the rebound rate was about 60% of the jounce rate) and blowoff was provided at the same velocity in each direction. The damping rates and blowoff velocities were varied and eventually an additional shock absorber was added at the number 2 roadwheels. Several design iterations were evaluated before arriving at the configuration referred to as concept A in Figure 10 and in Table 4.

The second approach was to soften the springs on the front three roadwheels (on each side) while maintaining the original springs on roadwheels 4 and 5. The softer springs were calculated to give a vertical natural frequency of 80 cpm (if they were used on all wheels).

This resulted in an effective natural frequency of 103 cpm for each of the design iterations leading to concept B. Shock absorbers were again used on the first, second, and last roadwheels.

Vehicle	Natural Freq. cpm	Damping Ratio	Shock Locations	Maximum Pitch degrees	Maximum Roll degrees
A	120	0.39	1,2,5	4.14	5.43
B	103	0.54	1,2,5	4.30	5.84
M551	120	0.62	1,5	4.13	5.66

Table 4 M551 and Derivatives Comparison

The results portrayed in Figure 10 and Table 4 indicate that it is possible to improve the overall vehicle performance. Concept A has an improved ride performance over the entire spectrum of terrain roughnesses and has, at the same time, not increased the maximum hull rotations experienced due to firing the gun. The results obtained with concept B show an even more dramatic improvement in ride quality over the standard M551, though the platform stability properties are slightly degraded in this case.

The real thrust of these results is, of course, not the "improvement" of a long established vehicle, the M551. It is rather the demonstration of the utility and power of the methodology presented. The models used in obtaining the results discussed in this paper are

(304)

extremely efficient, easy to use analysis tools. With these models the designer can evaluate various design tradeoffs between ride comfort and platform firing stability, or simply compare the performance of his concept against that of some known combat vehicle.

REFERENCES

1. Foss, Christopher F., "Armoured Fighting Vehicles of the World", Charles Scribner's Sons, 1977.

2. Lins, William F., "Human Vibration Response Measurement", TACOM Report No. 11551, June 1972.

3. Lee, R. A., Pradko F., "Analytical Analysis of Human Vibration", SAE Paper No. 680091, Jan. 1968.

4. Hoogterp, Francis B., "Interactive Vehicle Dynamics and Ride Evaluation Package", TARADCOM Report No. 12413, Nov. 1978.

5. Haug, E. J., Wehage, R., and Barman, N. C., "Dynamic Analysis and Design of Constrained Mechanical Systems", University of Iowa Technical Report No. 50, Nov. 1978.

6. Hoogterp, Francis B., "Platform Firing Stability Model", TARADCOM Report No. 12459, Sept. 1979.

7. Parent, R., "Integrated Engineering Service Test of XM551", TECOM Report No. DPS-1897, March 1966.

305